Progress Report

1. Kenneth Sassen PI, Vitaly Khvorostyanov Co-PI.

2. Improved CART Data Products and GCM Parameterizations for Clouds

3. We have made significant progress in developing algorithms to convert CART remote sensing data to useful cloud quantities. We have been particularly successful in characterizing the content of liquid stratus clouds using CART MMCR (K-band radar) and dual-channel microwave radiometer data, and identifying drizzle- and insect-corrupted radar returns. The algorithms were developed from our 1D adiabatic cloud model program and verified using CART IOP in situ data, and are currently being put on-line so as to allow the routine conversion of the CART datastream into useful cloud / radiation data quantities (e.g., vertical profiles of liquid water content and mean droplet radius). However, the difficulties inherent in characterizing ice and mixed-phase clouds are more formidable, and we intend to concentrate our algorithm development activities on these clouds using a standard multiple remote sensor ensemble: millimeter wave radar, polarization Raman (or micropulse) lidar, and microwave and infrared radiometers. Encouraging approaches involve using 2D-model cirrus radar simulations, and lidar signal slope and depolarization data to separate virga / precipitation heights from the base of the generating liquid clouds. Our research is facilitated by continued collaboration with V. I. Khvorostyanov, to use 2D cloud models with explicit microphysics and radiation to refine our cloud / radiation algorithms, and improve basic parameterizations employed in SCM / GCMs.

4. We have developed and applied to 1-year of CART remote sensing data an advanced algorithm using Raman lidar, millimeter wave radar, infrared brightness temperature, and dual-channel microwave radiometer data to determine cloud macrophysical properties, including cloud type and phase. A lidar / radar algorithm is being applied to deriving a similar 1-year climatology of cirrus cloud ice mass content and effective size.

5. Accomplishments over the last year:

a. Creation of a special series of 2D cloud model simulations with explicit microphysics and radiation to study the cycle of cirrus cloud growth and evaporation, and allow the assessment and parameterization of the net radiative effects of cirrus clouds, as a function of cloud temperature.
b. Developed a new parameterization to describe the particle size spectra in cirrus clouds to facilitate remote sensing algorithm development (Khvorostyanov and Sassen 2000).

c. Published in Sassen and Benson (2000) a parameterization for large-scale models of ice particle nucleation in cirrus cloud, as functions of temperature and updraft velocity, based on cloud parcel simulations of the homogeneous and heterogeneous nucleation modes.
d. Published in Wang and Sassen (2000) the first experimental evidence for the depletion of ozone from aqueous phase chemical reactions in continental stratus clouds, based on data from the 30 April 1994 IOP case study described in Sassen et al. 1999).
e. Participated in GEWEX Working Group 2 cirrus cloud modeling activities, including intercomparisons of parcel cloud model and 2-D cloud model simulations (papers under preparation headed by D. O.'C Starr).
f. Contributed lidar data and analysis to the paper describing the Central American smoke measurements during the 1998 CART cloud IOP (Peppler et al. 2000).
g. Developed and published in Mace and Sassen (2000) an algorithm based on adiabatic cloud parcel model simulations of water clouds for identifying the presence of drizzle and insect contamination of CART MMCR stratus cloud reflectivities and invalidates current algorithms.
h. Highlighted the capabilities of the ARM-sponsored scanning Polarization Diversity Lidar system in Sassen et al. (2000).
i. From the Ph. D. research of Z. Wang, "Cloud Property Retrieval Using Multiple Remote Sensors" (2000), developed a multiple remote sensor cloud property retrieval algorithm using Raman (or micropulse) lidar, the MMCR millimeter wave radar, infrared brightness temperature, and dual-channel microwave radiometer data. The algorithm has been applied to a 1-year record of Southern Great Plains CART remote sensing data to determine cloud macrophysical properties, including cloud heights, type, and phase. These results are being prepared for publication in Wang and Sassen (2000), and key figures are attached (see Section 6). A new lidar/radar algorithm is currently being applied to deriving a similar 1-year climatology of cirrus cloud ice mass content and effective size.

6. Figure description: Cloud property information derived from a 1-year (1998) record of Southern Great Plains CART Raman (or micropulse) lidar, the MMCR millimeter wave radar, infrared brightness temperature, and dual-channel microwave radiometer data, including: Figure 1. Monthly averages of the frequency of cloud occurrence as a function of height. Note that the peak occurrence of high, mid, and low level clouds happens in the months of October, February, and January, respectively. Figure 2. Statistics of monthly cloud type amount for the indicated cirrus, altostratus, altocumulus, stratus, stratocumulus, cumulus, nimbostratus, and deep convective clouds. Figure 3. Comparison of CART cloud type climatology with those derived from the

long-term ISCCP satellite findings, for all northern midlatitudes and for only over land.

7. Refereed Publications

Mace, G. G., and K. Sassen, 2000: A constrained algorithm for retrieval of stratocumulus cloud properties using solar radiation, microwave radiometer, and millimeter cloud radar data. *J. Geophys.* Res., **105** (in press).

Peppler. R. A., L. Ashford, C. P. Bahrmann. J. C. Barnard, J. R. Campbell, R. A. Ferrare, R. H. Halthore, N. S. Laulainen, J. A. Ogren, M. R. Poellot, K. Sassen, M. Splitt, and D. D. Turner, 2000: ARM Southern Great Plains site observations of the smoke pall associated with the 1998 Central American fire. *Bull. Amer. Meteor. Soc*., (submitted).

Sassen, K., and S. Benson, 2000: Ice nucleation in cirrus clouds: A model study of the homogeneous and heterogeneous modes. *Geophys. Res. Lett*., **27**, 521-524.

Sassen, K., J. M. Barnett, Z. Wang, and G. G. Mace, 2000: Cloud and aerosol research at FARS: The Facility for Atmospheric Remote Sensing. *Bull. Amer. Meteor. Soc*., (submitted).

Sassen, K., and Y. Takano, 2000: Parry arc: A polarization lidar, ray tracing, and aircraft case study. *Appl. Opt*. (submitted).

Wang, Z., and K. Sassen, 2000: Ozone destruction in continental stratus clouds: An aircraft case study. *J. Appl. Meteor.*, **39**, 875-886.

Wang, Z., and K. Sassen, 2000: Cloud type and macrophysical property retrieval using multiple remote sensors. To be submitted to *J. Appl. Meteor.*

8. Extended Abstracts

Khvorostyanov, V. I., and K. Sassen, 2000: A new parameterization for the crystal size spectra in cirrus and applications for remote sensing. Annual ARM Meeting, San Antonio.

9. Updated status.

Sassen, K., G. G. Mace, Z. Wang, M. P. Poellot, S. M. Sekelsky, and R. E. McIntosh, 1999: Continental stratus clouds: A case study using coordinated remote sensing and aircraft measurements. *J. Atmos. Sci.,* 56, **2345-2358**.

Sassen, K., **2000**. *Lidar Backscatter Depolarization Technique for Cloud and Aerosol Research*, in "Light Scattering by Nonspherical Particles: Theory, Measurements, and Geophysical Applications", M. L. Mischenko, J. W. Hovenier, and L. D. Travis, Eds. Academic Press, ISBN 0-12-498660-9, 393-416.

Khvorostyanov, V. I., and K. Sassen, **2001**. *Microphysical Processes in Cirrus and Their Impact on Radiation: A Mesoscale Modeling Perspective*, in "Cirrus", D. Lynch, K. Sassen, D. O'C. Starr, and G. L. Stephans, Eds. Oxford University Press, (in press).

Sassen, K., **2001**: *Cirrus Clouds: A Modern Perspective*, in "Cirrus", D. Lynch, K. Sassen, D. O'C. Starr, and G. L. Stephans, Eds. Oxford University Press, (in press).

Sassen, K, and G. G. Mace, **2001**: *Ground Based Remote Sensing of Cirrus Clouds,* in "Cirrus", D. Lynch, K. Sassen, D. O'C. Starr, and G. L. Stephans, Eds. Oxford University Press, (in press).

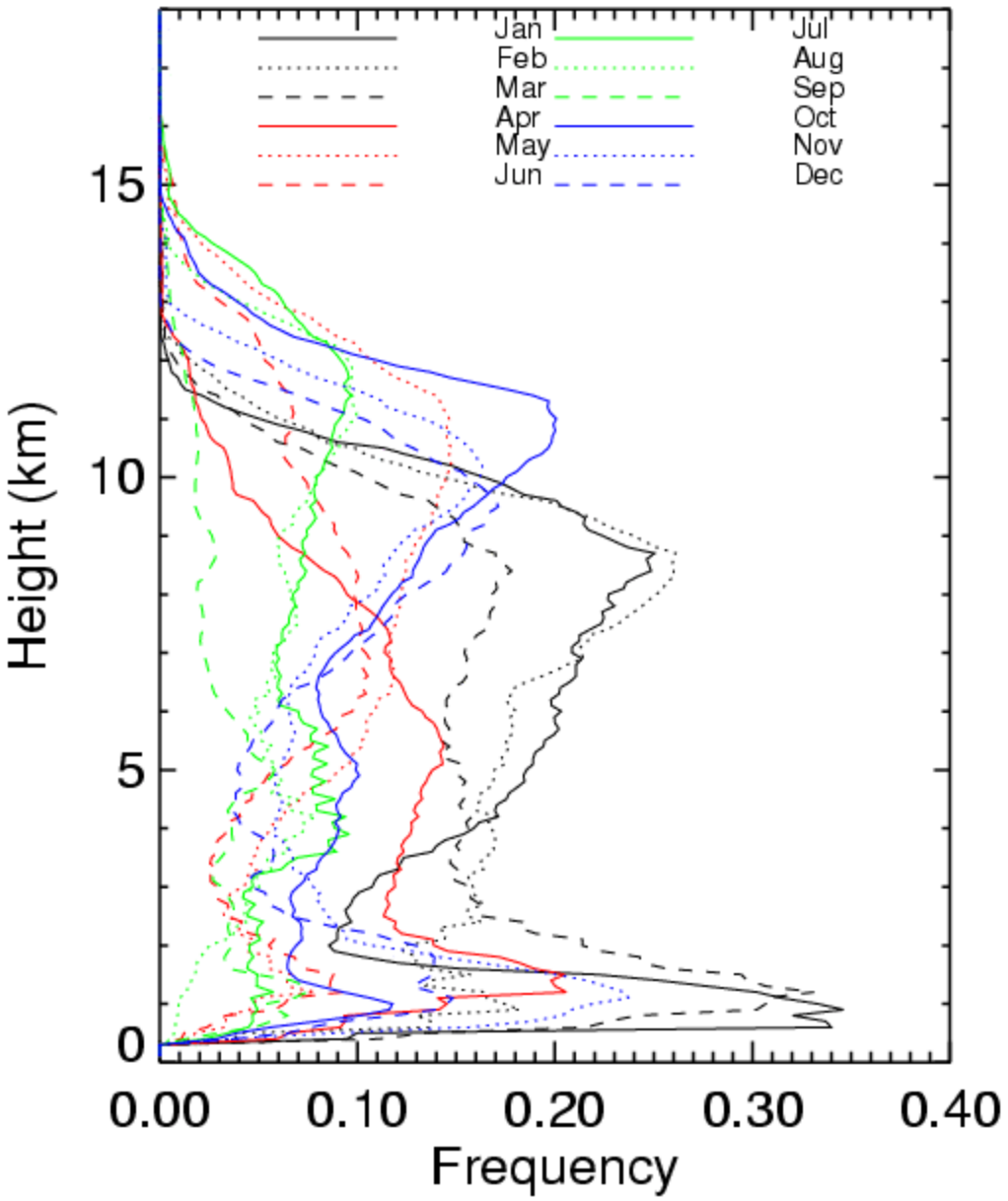

Figure 1: K. Sassen, University of Utah, 2000.

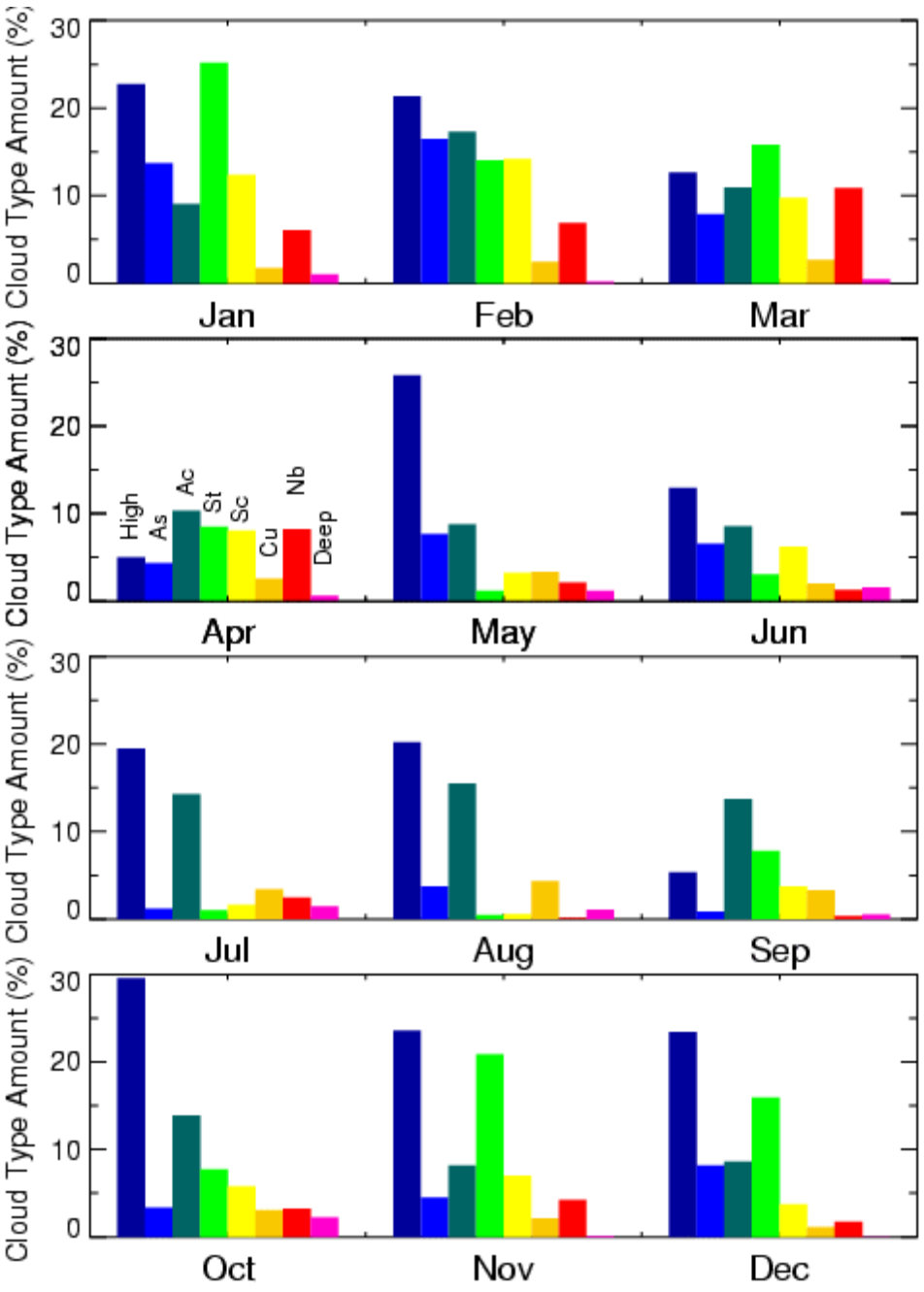

Figure 2: K. Sassen, University of Utah, 2000.

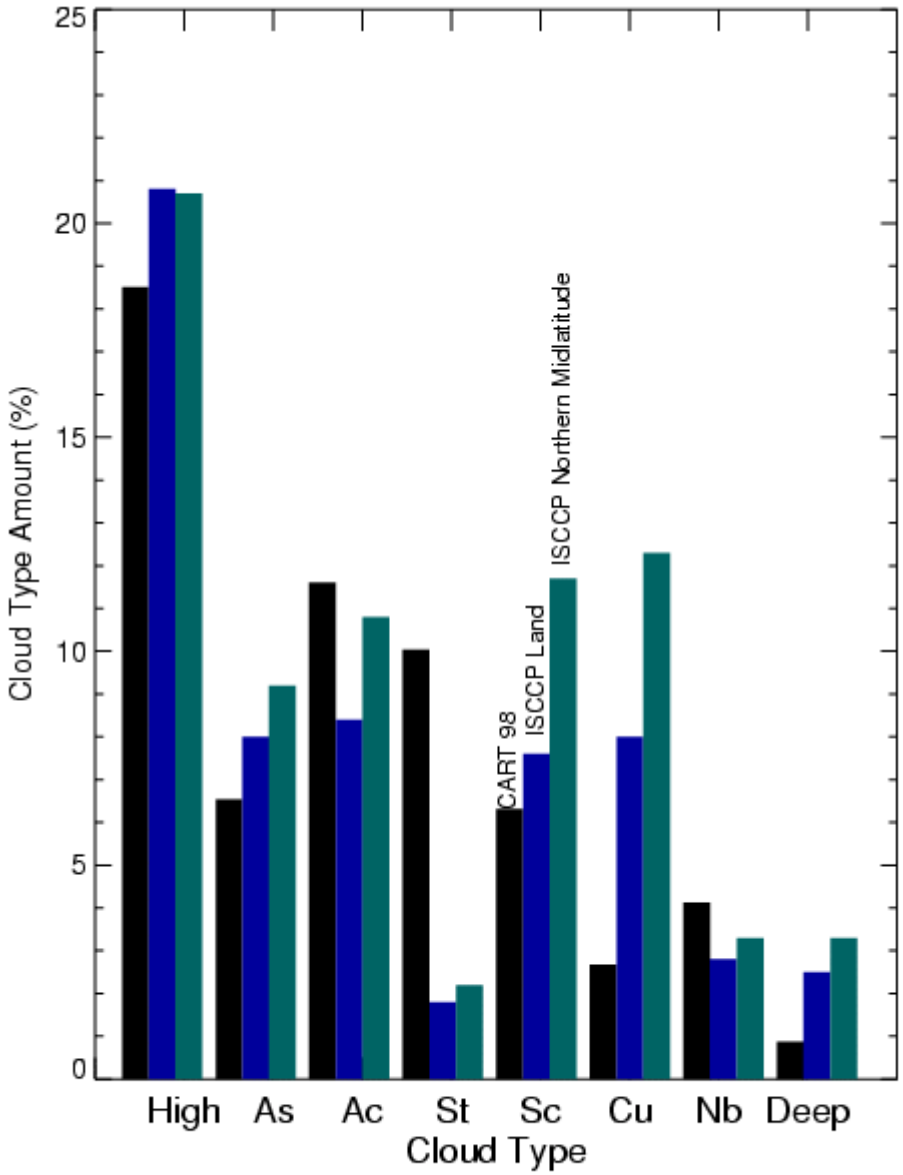

Figure 3: K. Sassen, University of Utah, 2000.